

## DIGITAL MAPPING OF MOUNTAIN SNOWCOVER UNDER EUROPEAN CONDITIONS

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### ABSTRACT

A method was developed for monitoring the snowcover in high mountain terrain such as the Swiss Alps which fulfills the specific needs of Europe and whose results are suitable as input into the runoff model by Martinec. The procedure includes the rapid classification of multi-temporal data for small watersheds with very high accuracy under all modifications caused by different illumination, sun angle, shadow effects, slope angle, exposure, terrain cover, etc. The method is based on a supervised classification technique, using a PPD-algorithm in general. In addition to the four Landsat-channels, a fifth artificial channel was created containing the average altitude information of each pixel and allowing a subdivision of the watershed in accordance to the requirements of the runoff model. Even in very small watersheds of about 40 km<sup>2</sup> the results achieved from Landsat data are at least as accurate as the ones gained from measurements of orthophotographs.

### INTRODUCTION

During recent years, the importance of earth resources satellites as a potential source for accurate and timely information has been recognized more and more in Europe. Under the leadership of the "European Space Agency" (ESA), in conjunction with its "Remote Sensing Working Group" (RSWG), the mission objectives were studied to identify specific demands and eventual contributions. ESA points out that the "main European emphasis is placed on the management and the conservation of known resources, rather than on the exploration and exploitation of new resources at national level" (ESA, 1977, p. 2). Even for developed regions such as Europe with reasonably complete resources information, earth observation satellites may play an important function in such areas as:

- monitoring the changing features of the European landscape (e.g., agriculture, land use, water resources)
- monitoring the coastal ocean areas (ESA, 1978, p. 1).

Within the field of water resources management, one of the most important potential applications to Europe is the operational monitoring of mountain snowcover. Mapping of the areal extent of the snowcover in its seasonal variations is closely correlated with surface runoff and, hence, is primarily undertaken for reservoir management and hydroelectric power station operations. Main attention has to

be given to mountain ranges such as the Alps, the Scandinavian mountains, the Pyrenees, etc., with their rugged topography, in and around which most of the hydroelectric power plants are located. For example: in Switzerland, 77.5%<sup>(1)</sup> of the total electric energy is produced by hydroelectric power plants, while in Norway, practically all electric energy is produced by hydroelectric power stations<sup>(2)</sup>.

It is the purpose of this paper to briefly review problems of digital snowmapping under the above mentioned specific European conditions and demands, using the Swiss Alps as the example, and to demonstrate the methods developed at the Department of Geography, University of Zurich, in collaboration with the Department of Photography, Swiss Federal Institute of Technology, Zurich. In addition, critical aspects and unsolved problems still under investigation shall be mentioned to meet the objectives of a truly operational snowmonitoring system.

## EUROPEAN REQUIREMENTS

The critical problem areas in applying satellite data to water resources application in the European high mountain ranges are:

- The need for guaranteed repetition coverage in a specific time sequence:  
In the long run, this problem can only be solved definitely by introducing an all-weather data acquisition system. At present the problem has to be tackled by extensive studies on the cloud coverage and in particular by developing methods to classify partly clouded Landsat scenes. Having gained a long-term knowledge on the position and the changes of the transient snowline of the study area, it should be possible to extrapolate the course of the snowline where it is cloudcovered from the situation in the cloudfree parts.
- The continuous and rapid transfer of the data to the user in almost real time:  
This problem was solved in principle for Europe with the establishment of the EARTHNET data acquisition and distribution system by the European Space Agency (ESA).
- The increase in the repetition rate up to a 6- to 9-day cycle:  
This could be achieved, disregarding the cloud problem, by either receiving Landsat-2 and -3 simultaneously (which has not been undertaken regularly at present over Europe) or by combining Landsat with very high resolution weather satellite data.
- The variability of the mountain terrain and the smallness of the individual catchment areas in relation to the high demands of accuracy standards:  
Very accurate classification methods are required which are applicable under all different modifications of sun position, sun angle, illumination, slope angle, exposure, shadow effects, terrain cover, etc., as well as very precise measurement techniques.

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(1) Valid for the hydrologic year 1977/1978, as reported in NZZ, No. 275, November 25, 1978.

(2) Odegaard and Ostrem, 1977, p. 5.



- The incorporation of automatic change detection methods:  
To directly compare multitemporal data-sets, geometric as well as radiometric corrections are needed. Weather conditions in the Alps vary greatly even within the same Landsat scene. Therefore a standardization of the data prior to a classification is of utmost importance<sup>(1)</sup>.
- The combination with data received from other data acquisition systems:  
Data from various acquisition sources should be united in such a way that they become directly comparable; e.g., by geocoding the various data and by its organization in geographic information systems, spatially-oriented processing can be performed or the data can be used as input into environmental models (e.g., runoff models). This enables not only the combined utilization of a variety of information from different origin, but also the fast retrieval of the needed information for specific applications.

In conclusion, future operational snowcover measurement techniques will have to incorporate the following facilities (ESA, 1977, p. 15):

- automatic change detection
- correlation with terrain models
- optimum combination of meteorological and earth resources satellite data
- input of satellite data into environmental models (e.g., runoff model).

## STUDY AREA

The representative basin, the Dischma Valley, as used and surveyed for years by the Swiss Federal Institute for Snow and Avalanche Research, Weissfluhjoch/Davos, was chosen as the main study area. The Dischma Valley lies in the central part of Grisons and extends from Davos toward the southeast. The part above the water gage at 1668 m MSL (Figure 1) covers an area of 43.7 km<sup>2</sup>. The highest surrounding peaks reach altitudes of more than 3000 m MSL.

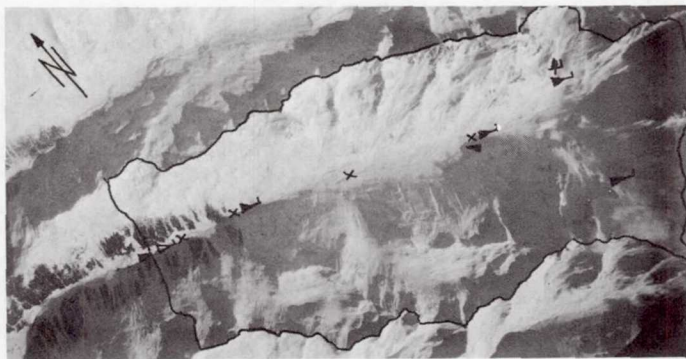
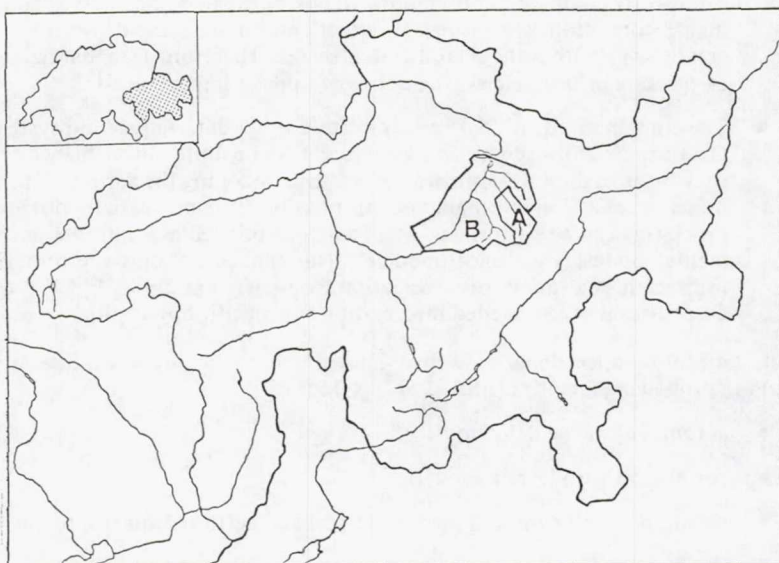
In a further step, the study area was extended to the upper drainage basin of the Landwasser in the region of Davos to get results from a larger watershed. It covers an area of approximately 290.5 km<sup>2</sup> with altitudes between 1,000 – 3,100 m MSL.

## METHODOLOGY

Methodological aspects of snowmapping from satellites are discussed by Rango and Itten (1976) and Haefner and Muri (1978). In an operational system there always has to be a tradeoff between accuracy and time. In snowmapping, priority irrevocably has to be given to time, since no delay in the transference of the vital information to the user can be accepted. On the other hand, the demands for high accuracy and for detailed statistical documentation have been established clearly in Europe and consequently have to be considered as well. In addition, emphasis has to be given to the processing of multitemporal data acquired under very different atmospheric and illumination conditions. All these aspects have to be taken into account, setting up a compatible automated classification system in accordance to the available equipment and the financial funds.

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(1) Research in this direction was undertaken by Staenz (1976/78) etc.



Dischma Valley: airphoto approx. 1:140,000 of Febr. 20, 1976

- |                        |                                    |
|------------------------|------------------------------------|
| — representative basin | ▶ stream flow gage                 |
| ⌵ precipitation gage   | ⊕ automated meteorological station |
| ▼ totalizer            | × snow marker                      |

Figure 1. Test sites Dischma Valley (A) and Landwasser (B), Davos - Grisons - Switzerland

Finally, the data processing has to be accompanied by various supporting activities, such as:

- ground observations and measurements
- studies of the spectral characteristics of snow
- aerial underflights, etc.

These supporting activities are indispensable for a better understanding of the study area and of the study object – snow – in its diurnal and seasonal variations, for an optimal selection of the training samples (in a supervised classification system) and for a verification of the results.

## DIGITAL DATA PROCESSING

### Approach

To meet the criteria as set up in the previous chapters, as well as the requirements for an input into a runoff model<sup>(1)</sup>, the following concept was realized:

- supervised classification technique based on a very careful selection of the training samples
- specific determination of the transition zone between the totally snow-covered and the snowfree area
- construction of a fifth “artificial” Landsat channel containing the digital terrain model
- presentation of the results in maplike and tabular form.

### Preprocessing

Several preprocessing steps are undertaken including:

- reformatting of the data in such a way that they are best organized for the available hardware and software
- radiometric corrections of the sixth line effect (scanline standardization)
- presentation of the digital data in geometric corrected images with the OPTRONICS-Photomation P-1700.

### Data Classification

An interactive image interpretation system, IBIS (Interaktives Bild-Interpretations-System), was developed to satisfy the specific needs as discussed (Fäslar, 1978). The system (Figure 2) is structured in modular form, which enables an easy addition of new components or the use of a subset only. It consists of three parts:

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(1) Runoff model developed by Martinec (1977) asking for a delineation of the watershed into different altitudinal zones.



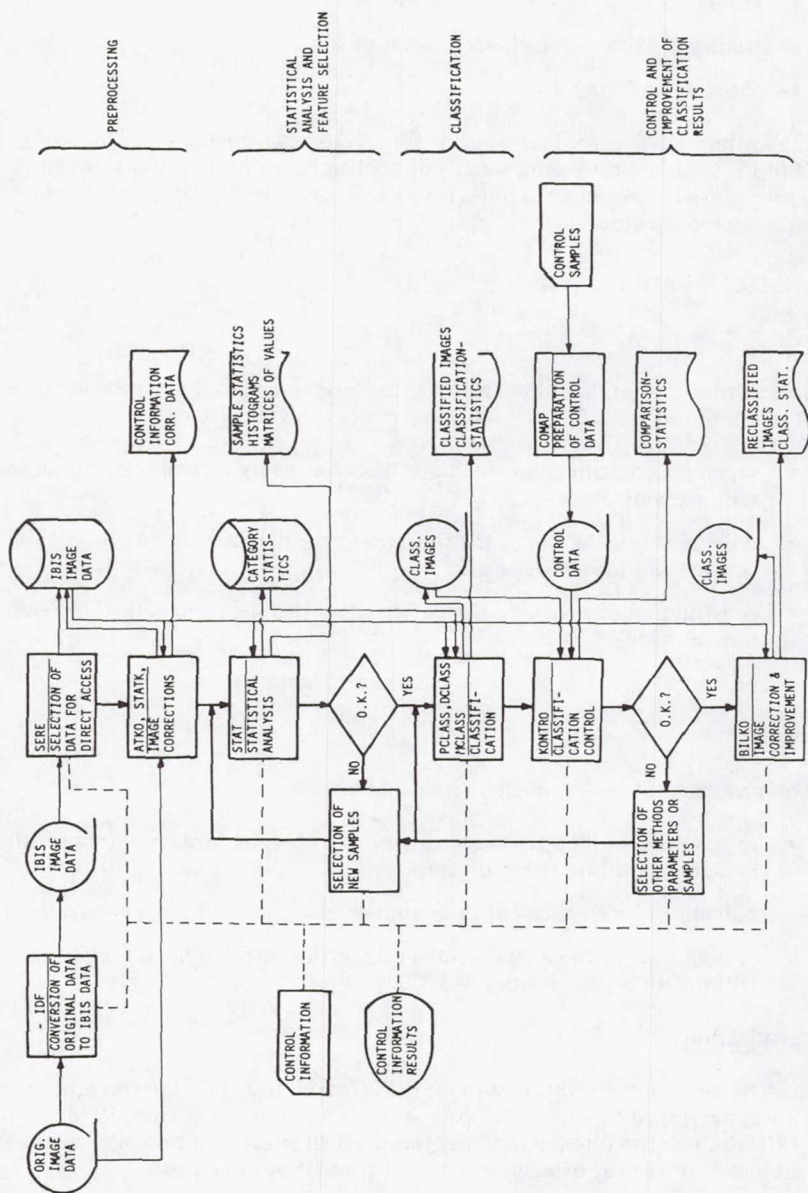


Figure 2. IBIS - Interactive Image Interpretation System (after Fasler, 1978)

- preprocessing as discussed in the previous chapter
- statistical analysis of the training samples (or groups of samples)
- classification based on the results of the previous steps with different algorithms such as:
  - parallel epiped mode (PPD)
  - maximum likelihood
  - euclidean distance (D-class).

In a supervised classification system the most critical item on which the quality of the results depends entirely is the selection and definition of the training samples. Therefore, specific care has to be given to this problem. To allow a precise measurement of the snowcover, three final categories are defined:

- totally snowcovered area
- transition zone
- totally snowfree area.

To achieve a clear separation, these three categories have to be subdivided into various sub-categories as shown in Figure 3. A first selection of the sub-categories is undertaken with reference to the well-known surface features. They are exactly located by using topographic and thematic maps and rechecking in the field.

The exact location of the training samples within the data-set is done by using geometric corrected satellite images enlarged with the Photomation system to such an extent that each individual pixel is recognizable. At the same time, the image is overlaid with a grid (20 x 20 pixels) to facilitate the location of the image coordinates. All training samples are tested regarding their statistical characteristics (Figure 4). If necessary, corrections such as shifts in the extension or position of the training samples, etc., are made to reach a final selection.

Several tests showed that a definite classification can be undertaken by using band 5 and 7 (Gfeller, 1975; Stirnemann, 1976). This remains valid as long as no bright objects such as concrete, white rocks, etc., or snow under dense needleleaf forest<sup>(1)</sup> are found in the test area and no classification of the snowcover into different snowtypes is desired. To test the separability of the selected training samples, they are represented in graphical form (program ELLPLT for HP 9830). Ellipses are drawn around the center of the meridian of each sample with the half-axis proportional to the standard deviation (Figure 5). This presentation illustrates the orientation of the training samples in a two-dimensional feature space and allows the determination of the boundaries for the PPD-classification. Figure 5b shows that if a larger part of the snowcover lays in shadow, the accuracy of the classification will be affected considerably.

The PPD-algorithm - by far the simplest and most economical one - offers good possibilities as long as not too many different variables (spectral bands) and not too many

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(1) Itten (1977) used bands 4, 5, and 7 to overcome this problem.

No.	sub-category	category	portion of snowcoverage
1	snow, dry, in sun	totally snowcovered area	100 %
2	snow, metamorphic, in sun		
3	snow, in shadow		
4	snow, intermixed with few rocks, in sun		
5	snow, intermixed with some snowfree spots		
6	snow, half intermixed with rocks	transition zone	50 %
7	snow, intermixed with snowfree spots ( 50 %)		
8	snow, intermixed with snowfree spots ( 50 %)		
9	dense needleleaf forest, snow-free, in sun	totally snowfree area	0 %
10	open needleleaf forest and shrubs, snowfree, in sun		
11	shrubs with some trees, snowfree, in sun		
12	alpine zone, snowfree, in sun		
13	alpine pastures with shrubs, snowfree, in sun		
14	meadows, snowfree, in sun		
15	settlements, snowfree, in sun		
16	open water, in sun		

Figure 3. Training samples for snow classification



June 8th, 1976	Sub-categ.	channel 4		channel 5		channel 6		channel 7	
		$\bar{x}$	$\sigma$	$\bar{x}$	$\sigma$	$\bar{x}$	$\sigma$	$\bar{x}$	$\sigma$
	1	127.00	0.00	127.00	0.00	127.00	0.00	62.90	1.93
	2	126.27	2.05	127.00	0.00	127.00	0.00	45.75	3.97
	4	118.10	17.44	122.31	11.88	121.17	13.74	44.19	7.39
	5	118.78	11.40	125.61	4.37	125.19	4.18	45.94	5.64
	6	70.67	19.25	81.11	23.02	74.86	21.50	23.54	6.98
	7	68.83	16.60	84.38	20.17	83.69	17.48	28.75	4.58
	8	52.04	11.75	62.96	14.33	68.83	11.70	26.27	3.87
	9	13.30	1.51	12.28	2.09	24.32	5.19	11.20	2.83
	10	20.65	3.34	23.07	5.18	50.45	9.53	28.84	5.73
	11	16.64	1.59	16.62	2.53	38.11	6.33	19.04	4.17
	12	32.70	3.31	41.61	4.60	68.29	6.07	33.80	3.74
	13	22.55	2.66	25.74	3.94	51.99	10.55	26.50	6.71
	14	20.70	2.19	19.77	2.83	79.30	14.93	44.49	9.45
	15	27.98	3.34	31.33	4.83	53.44	8.11	24.56	5.76
	16	17.21	0.83	10.04	0.46	5.79	1.10	0.00	0.00

August 7th, 1976	Sub-categ.	channel 4		channel 5		channel 6		channel 7	
		$\bar{x}$	$\sigma$	$\bar{x}$	$\sigma$	$\bar{x}$	$\sigma$	$\bar{x}$	$\sigma$
	1	127.00	0.00	127.00	0.00	127.00	0.00	60.38	1.93
	2	112.14	11.17	124.89	5.47	123.16	7.93	40.65	4.62
	3	14.80	2.31	13.03	2.70	11.97	3.05	2.93	1.34
	4	106.90	10.37	124.05	5.62	123.15	6.96	46.40	4.03
	6	73.60	12.65	88.63	17.05	83.07	16.42	25.87	5.49
	8	50.09	18.41	61.08	23.15	73.30	18.39	30.15	7.05
	9	11.04	1.51	9.45	1.92	20.23	5.29	9.31	3.04
	10	16.23	3.95	15.75	5.17	41.67	7.32	21.37	3.99
	11	11.76	0.80	10.21	0.87	26.38	2.32	13.01	1.40
	13	18.60	3.32	20.34	4.47	50.90	5.51	26.54	3.86
	14	19.34	1.77	18.43	1.72	81.00	6.94	46.46	4.48
	15	24.53	2.90	27.22	3.93	47.49	6.45	21.99	4.45
	16	16.93	0.92	9.43	0.67	6.71	1.35	0.62	0.80

Figure 4. Statistics (mean value and standard deviation) for sub-categories (Numbers as in Figure 3) (after Urfer, 1978)

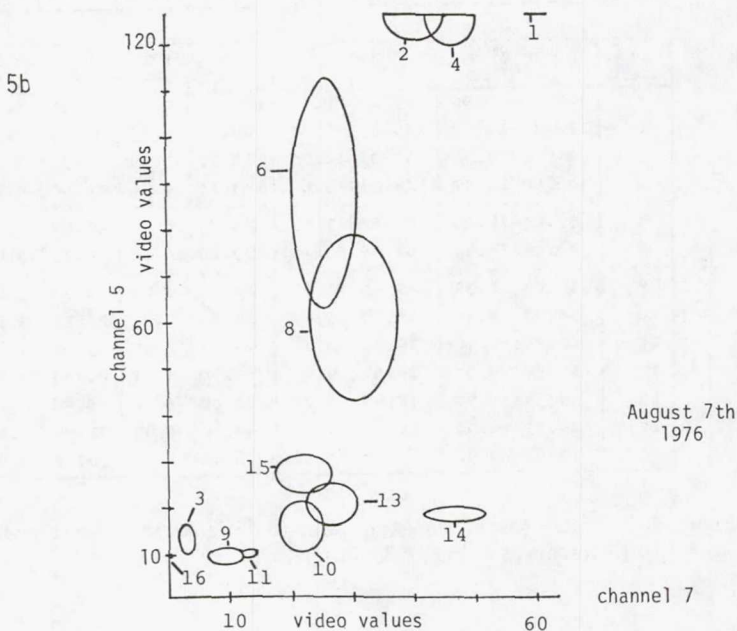
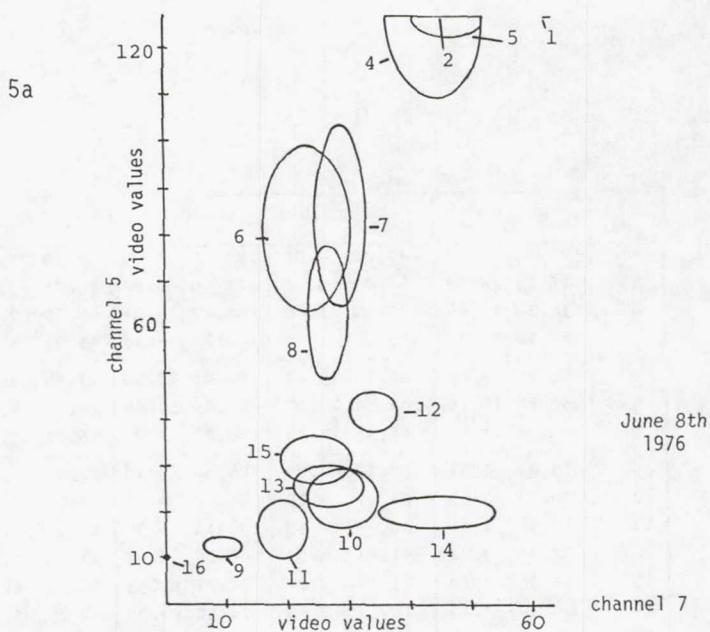


Figure 5. Graphical presentation of sub-categories (as in Figure 3) in two-dimensional feature space: Ellipses represent one standard deviation from mean values (after Urfer, 1978)

different sub-categories are used. The determination of the boundaries becomes very difficult if more than three variables and more than ten sub-categories are included. Under these circumstances, other algorithms than PPD should be used.

The snow-classification for the Dischma Valley test site is demonstrated in Figure 6 for June 8 and August 7, 1976, and for the Landwasser test site in Figure 7 for June 8, 1976.

### Altitude Zone Channel

The basic idea was to create a fifth artificial Landsat channel, which adds to each pixel the information on the altitude zone to which it belongs<sup>(1)</sup> (to be called "altitude zone Landsat channel").

In a first step, the boundaries of the drainage basin as well as of the selected contour lines dividing the altitude zones (Figure 8) have to be delineated. This information is retrieved from a topo-map (1:50,000). To perfectly match the satellite image with the map, geometric corrections are necessary. Specific software was developed adaptable to the available equipment (OPTRONICS Photomation P-1700)<sup>(2)</sup>. Afterwards, the corrected image is enlarged to the map-scale.

To precisely superimpose the satellite image onto the map, striking terrain points such as corners of woods, river outlets or junctions, mountain peaks, etc. are used, which are easy to identify on both presentations and which can be marked by map as well as satellite coordinates<sup>(3)</sup>.

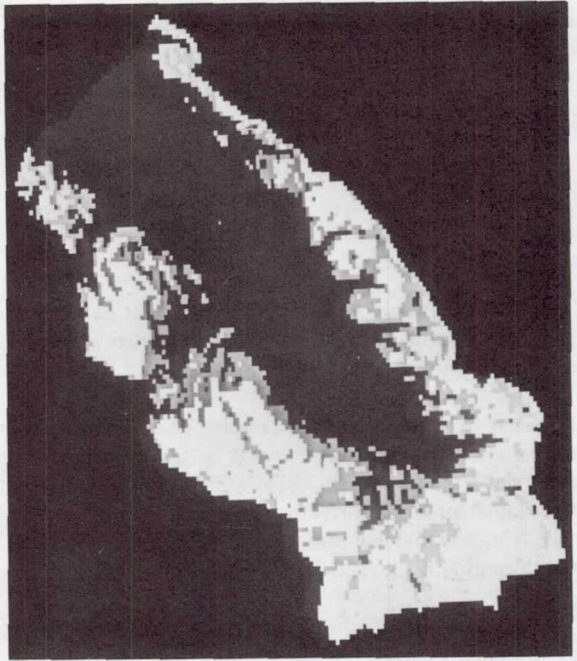
In a second step, the drainage basin is delineated and the terrain digitized by transferring the boundaries of the basin and of the altitude zones from the map onto the maplike satellite image (scale 1:50,000) and by orienting the scanline along the main axis of the digitizer plate. First, two reference points are registered with their satellite coordinates. Then the boundaries are digitized in form of satellite coordinates and stored in the HP-9800 computer.

It certainly would be possible to gain the digitized information directly from the map and to use the satellite image only for the determination of the reference points and the orientation of the digitizer. But to achieve maximum accuracy, the described technique is more feasible.

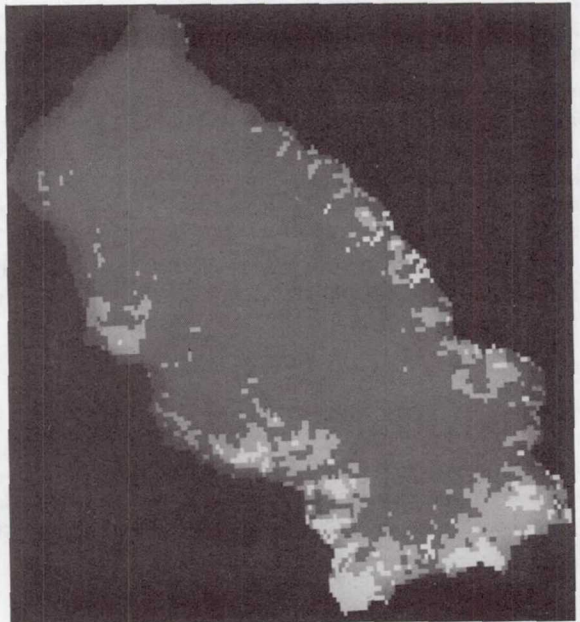
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- (1) Instead of altitude, other subdivisions of the study area, into natural or administrative units, etc., would be possible.
  - (2) We are aware that much more sophisticated equipment and techniques exist to fulfill this purpose, e.g., developed for the IMAGE-100 (Dallam, 1975). Similar developments are underway at Zurich, based on the interactive PDP-11/RAMTEK interactive image-analysis system.
  - (3) Satellite coordinates mean the position of a pixel in a Landsat scene expressed by line and column numbers.



June 8, 1976



August 7, 1976



white = totally  
snowcovered  
gray = transition  
zone  
black = totally  
snowfree

Figure 6. Snow classification of Dischma Valley test site (after Urfer, 1978)

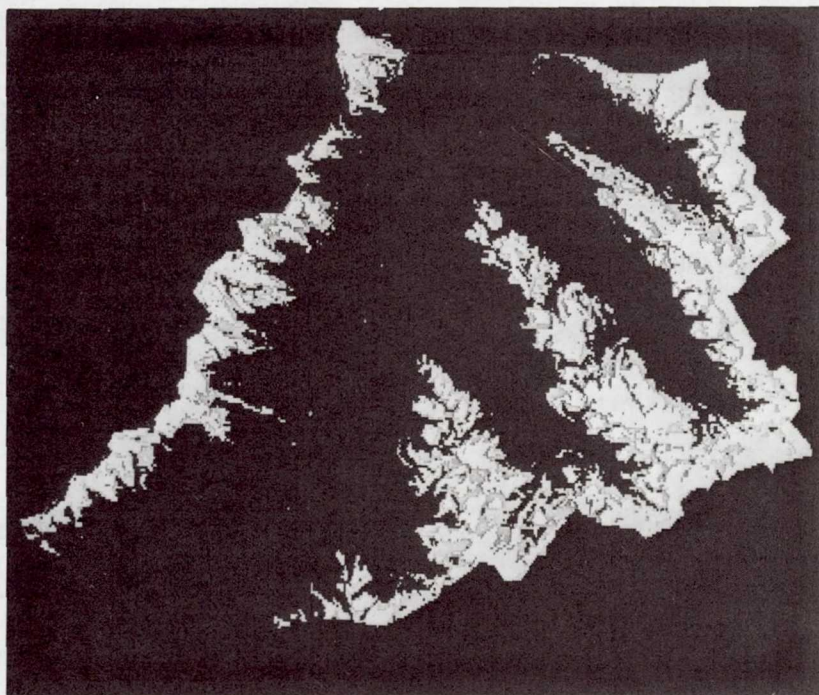


Figure 7. Snow classification of Landwasser test site, June 8, 1976  
(after Urfer, 1978)

In a third step, the polygonal boundaries as registered are transferred from satellite coordinates into a grid system. The area within a polygon receives a binary figure and by its combining, the specific code for each altitude zone is established as follows:

- the highest zone above 2,600 m: 0 0 1
- the medium zone between 2,600 – 2,100 m: 0 1 1
- the lowest zone below 2,100 m: 1 1 1
- all parts not included in the test site: 0 0 0

In a last step, this information has to be added pixelwise to the video data of the four Landsat channels. Now, each pixel is attached to a specific altitude zone. All other pixels, which do not belong to one of these zones, are not taken into account in the classification or the output.

This method allows a very precise delineation and subdivision of test sites of any shape at will and an individual calculation of the extent of the snowcover for each areal unit. With the Photomation system, the altitude zones are presented in different graytones, as shown in Figure 9 for the Dischma Valley and in Figure 10 for the Landwasser test site. Comparisons were made between different Landsat scenes and



	DISCHMA			LANDWASSER		
	Pixels	%	km <sup>2</sup>	Pixels	%	km <sup>2</sup>
1. high zone 2,600 m MSL	2,176	22.5	9.82	6,605	10.3	29.81
2. medium zone 2100-2600 m MSL	5,467	56.5	24.68	29,338	45.6	132.43
3. low zone 2,100 m MSL	2,038	21.0	9.20	28,409	44.1	128.24
Total test site	9,681	100.0	43.70 (16.87 mi <sup>2</sup> )	64,352	100.0	290.48 (112.18 mi <sup>2</sup> )

Figure 8. Altitude zones of Dischma Valley and Landwasser test sites

with measurements from orthophotos. They produced an accordance in the size of the altitude zones of 0.1% between three Landsat scenes and of 0.5% with the orthophoto measurements.

### Results

The areal measurements of the snowcover for June 8 and August 7, 1976, are summarized in Figure 11. Comparisons with a visual interpretation of orthophotos (1:50,000) and areal measurement with a Quantimet showed a very good accordance in the lower and medium altitude zone. The maximum difference in the portion of the snowcovered area was 1.8%. For the highest zone, the results differed up to 13.5%; but a careful evaluation lead to the conclusion that the Landsat measurements are more reliable.

The Landsat-altitude-channel as described has just to be produced once and can be used again for each new scene. The test area in the new image is shifted and rotated until it matches the one in the original image. The same reference points are utilized. The difference between the satellite coordinates of the new scene and the coordinates of the original image gives the shifting and rotating vectors. The more reference points used, the more accurate the calculation becomes.

An additional advantage means that part of the training samples (e.g., open water, settlements, snowfree forests, shrubs, pastures, etc.) can be used again directly. Their satellite coordinates are already registered. Other samples have to be newly established every time, especially the ones for the transition zone between the snowfree and snowcovered areas.



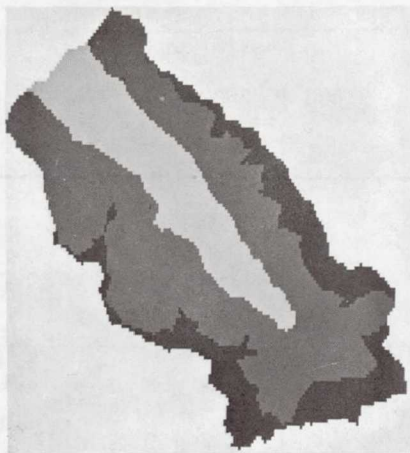


Figure 9

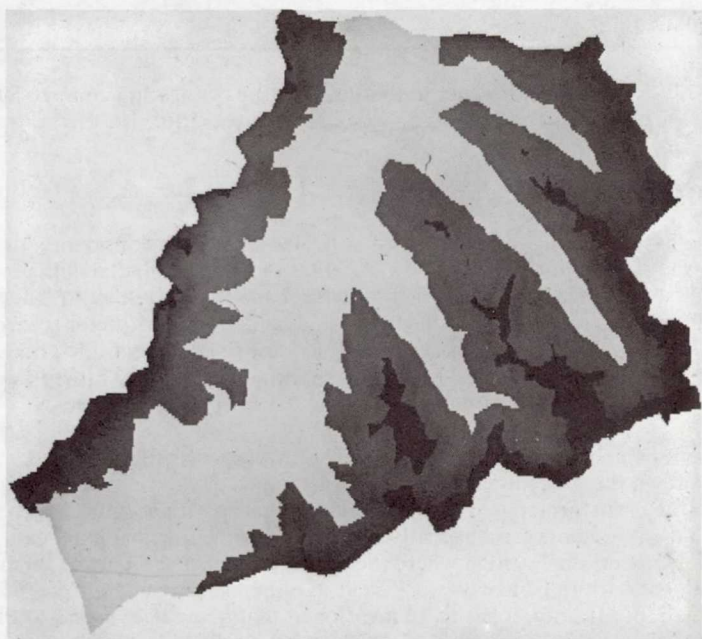


Figure 10

Figures 9 and 10. Altitude zone channel of Dischma Valley and Landwasser test sites (after Urfer, 1978)

	Altitude zone			Test site
	> 2,600 %	2600-2100 %	<2,100 %	total %
DISCHMA June 8, 1976				
Landsat	80.2	44.1	0.2	43.3
Orthophoto	72.9	42.3	0.0	-
DISCHMA August 7, 1976				
Landsat	36.0	5.4	0.0	11.1
Orthophoto	22.5	5.4	0.3	-
LANDWASSER June 8, 1976				
Landsat	78.4	37.9	0.0	25.3
Orthophoto	-	-	-	-

Figure 11. Extent of snowcover in the three altitude zones and comparison with measurements on orthophotographs (after Urfer, 1978)

### Time Expenditure

Since time has been designed as the most critical factor, some considerations shall be added on the time requirements for the different parts of the digital data processing system. As a reference basis, the larger test site, Landwasser (Figure 1), of approximately 300 km<sup>2</sup>, is taken and assumed that an experienced interpreter is carrying out the classification. The average time expenditures for the different operations are listed in Figure 12. In principle, they reveal that the method may satisfy the time requirement for a fast classification as well as the demand for high accuracy.

But it has to be pointed out clearly that quite a few aspects are not considered, which may slow down the procedure. First, the transference of the data from the ground station to the user (forming of the CCT's) is not taken into account. Secondly, the average time of 14 hours can be greatly shortened on one side and extended on the other. In an operational system where the altitude channel and part of the training samples do not have to be newly established, the time requirements could be reduced to about half. Contrarily, it has to be mentioned that immediate access to the computer is not always granted and longer waiting periods may have to be included. So, the figures as stated in Figure 12 cover just the time of active work for the interpretation.

Operation	approximate time expenditure in hours
A preprocessing	1
B preparation of altitude zone channel	5
C combination of four Landsat- channels with altitude zone channel	1/4
D selection and location of training samples	3
E statistics, corrections, etc.	2
F classification and presentation in a geometric corrected image	3
t o t a l	14 1/4

Figure 12. Time expenditure for the different operations of the snow classification system for the Landwasser test site (approximately 300 km<sup>2</sup>) (after Urfer, 1978)

## CONCLUSIONS AND OUTLOOK

Today, the space segment for an automated monitoring of the snowcover in Europe can be regarded as operational. The severest restrictions originate from the cloud problem. Therefore, a classification of partly clouded Landsat scenes has to be reached, which asks for a perfect separation of snow and clouds under all different modifications by illumination, atmospheric effects, and terrain characteristics. To achieve this objective, a channel in the 1.55 – 1.75  $\mu\text{m}$  region is essential. In addition, the repetition cycle has to be shortened during the critical days of the melting period to about 6 days.

Regarding the ground segment, a rapid production of the CCT's and their transference to the user still should be improved. The methodology for an operational classification of the data has to be developed and rationalized further toward:

- automatic change detection
- faster and more economical procedures
- combining the results with other information (e.g., input into a geographic information system)



- separating not only the snow from the background but subdividing the snowcover itself (e.g., wet/dry snow; freezing/thawing line; thick/thin cover, etc.

In doing so, the high accuracy standards as needed in Europe have to be preserved. This becomes especially important when classifying larger watersheds than investigated at present.

## ACKNOWLEDGEMENT

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## REFERENCES

- ESA: European Remote Sensing Space Programme. Mission Objectives and Measurement Requirements. ESA/EXEC(77)3, Paris, April 1977.
- ESA: Interim Remote Sensing Programme Board – European Remote Sensing Programme. ESA/C(78)102, Paris, September 1978.
- Fasler, F.: IBIS – an Interactive Image Interpretation System. Proc. ISP-IUFRO Int. Symp. on Remote Sensing, Freiburg i.Br., FRG, July 1978 (to be published).
- Haefner, H.: Snow Mapping and Land Use Studies in Switzerland. Landsat-2 Final Report to NASA, Zurich 1977.
- Haefner, H.: Snow Cover Monitoring from Satellite Data under European Conditions. Proc. ISPRA-Course, JRC, Italy 1978 (to be published).
- Haefner, H., and R. Muri: Methodology of Snowmapping. Proc. ISP-IUFRO Int. Symp. on Remote Sensing, Freiburg i.Br., FRG, July 1978 (to be published).
- Itten, K. I.: Approaches to Digital Snow Mapping with Landsat-1 Data. Proc. NASA Workshop on Operational Applications of Satellite Snowcover Observations, South Lake Tahoe, Calif., Washington, D.C., 1975.

- Martinec, J.: Hydrologic Basin Models. Proc. ISPRA-Course, JRC, Italy 1978 (to be published).
- Ødegaard, H. A. and G. Østrem: Application of Satellite Data for Snow Mapping. Norges Vassdrags - og Elektrisitetsvesen, Rapport 9-77, Oslo, 1977.
- Rango, A., and K. I. Itten: Satellite Potentials in Snowcover Monitoring and Runoff Prediction. Nordic Hydrology, 7, 1976;
- Seidel, K.: Digitale Bildverarbeitung. Technical Report, Swiss Federal Institute of Technology, Zurich, 1976.
- Staenz, K.: Radiometrische Untersuchungen über das Reflexionsverhalten von Schnee. M.S.-Thesis, Department of Geography, University of Zurich, 1976 (unpublished).
- Staenz, K.: Atmosphärische Korrekturen von Multispektraldaten des Erderkundungssatelliten Landsat-2. Ph.D.-Thesis, University of Zurich, 1978.
- Stirnemann, H.-P.: Schneedecke und Schneegrenzzone in Satelliten-aufnahmen. M.S.-Thesis, Department of Geography, University of Zurich, 1977 (unpublished).
- Urfer, H.-P.: Routinemässige Schneekartierung in hydrologischen Einzugsgebieten mit Landsat-Daten. M.S.-Thesis, Department of Geography, University of Zurich, 1978 (unpublished).